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CONSTRAINTS ON THE DEPTH AND GEOMETRY OF THE MAGMA CHAMBER OF THE OLYMPUS MONS VOLCANO, MARS; *M.T. Zuber*, Geodynamics Branch, Code 621, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, *and P.J. Mouginis-Mark*, Planetary Geosciences Division, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, HI 96822.

The summit caldera of the Olympus Mons volcano exhibits one of the clearest examples of tectonic processes associated with shield volcanism on Mars [1,2]. Within the 80 km diameter structure are six nested craters that indicate that the volcano edifice has undergone multiple collapse episodes [1]. Also found within the caldera are numerous compressional (ridges) and extensional (graben) tectonic features. Analysis of the topography of the caldera as derived from stereophotogrammetry [3] shows that the central portion of the largest (and oldest) crater, which contains radial and concentric ridges, represents a topographic low, while the crater perimeter, which is characterized by concentric graben, forms a topographic high. The relationship of the summit topography to the tectonic features, in combination with photogeologic evidence for basalt-like resurfacing of the caldera floor [4,5], is believed to indicate that a large lava lake has cooled and subsided due to pressure reduction in the underlying magma chamber.

The radial distance from center of the transition from concentric ridges to concentric graben within the oldest crater provides a constraint on the geometry and depth of the subsurface magmatic reservoir at the time of subsidence. In this study we use this constraint to investigate the size, shape and depth of the reservoir. Our approach consists of calculating radial surface stresses (σ_{rro}) corresponding to a range of subsurface pressure distributions representing an evacuating magma chamber. We then compare the stress patterns to the observed radial positions of concentric ridges and graben. We solve the problem by employing a finite element approach using the program TECTON [6]. An axisymmetric geometry and linear elastic material properties are assumed. The magma chamber is modeled as an elliptically-shaped source; nodes within the ellipse are characterized by a stress condition that represents an instantaneous pressure drop. Parameters of interest include the horizontal (a) and vertical (b) dimensions of the magma chamber and the depth to the top of the chamber (d). The following boundary conditions are imposed: vanishing horizontal (u) displacements at the center of symmetry of the volcano; vanishing vertical (w) displacements at depths much greater than the crater radius; and vanishing horizontal and vertical displacements at radial distances far from the crater rim. Numerical analyses were performed to assure that solutions were not sensitive to the far field boundary conditions.

Examples of radial surface stress distributions for a series of magma chamber depths with $a=R_c$ (where R_c is the crater radius) and $b/a=0.5$ are shown in Figure 1. The state of stress as inferred from the ridges and graben changes from compression (-) to extension (+) at a radial distance (r) of approximately $0.53R_c$ [5], where R_c is the crater radius (32 km). For these assumed parameters, the corresponding pattern of stresses indicates that the top of the magma chamber at the time of subsidence was located at a depth of less than $0.5R_c$ (best-fit range $8 \leq d \leq 16$ km). The best-fit depth is not very sensitive to the aspect ratio of the chamber (Figure 2), the difference in Young's Modulus between the chamber and surroundings (for $E_{mc}/E_s<.1$), or details of the imposed pressure distribution. However, as shown in Figure 3, depth is highly sensitive to magma chamber width. The magma chamber is unlikely to be markedly narrower than the crater; if it is wider, then Figure 3 illustrates that a shallower maximum depth than determined from Figure 1 is implied. Superposition of near-summit stresses associated with self-compression of the volcano [7] would also shift the maximum to shallower depths. We thus conclude that if concentric ridges and graben within the largest and oldest crater in the Olympus Mons caldera complex formed as a consequence of subsidence related to magma chamber withdrawal, then the magma chamber was located within the volcanic edifice, at a depth less than half the crater radius. This result is in agreement with our previous analysis that assumed simpler chamber geometries [8,9]. With appropriate scaling for the difference in gravity between Mars and Earth, this depth is similar to that observed for the magma chamber beneath the Kilauea caldera [10], which would suggest a gross similarity of internal structure of the two shields.

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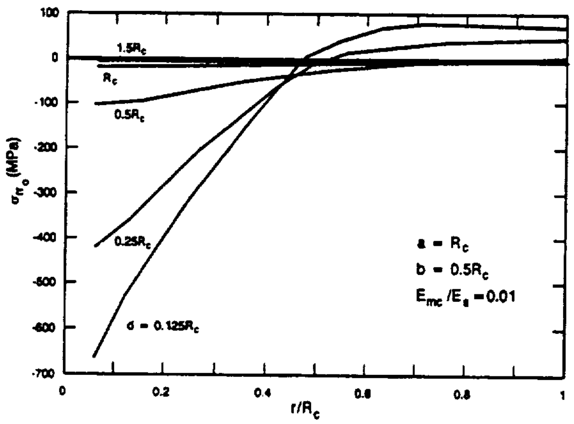

Figure 1. Radial surface stress (σ_{rro}) vs. distance from the crater center (r/R_c, where R_c= crater radius) due to deflation of a subsurface magma chamber. Stress patterns are shown for a range of depths (d). Assumes an elliptical chamber with width $a=R_c$ and height $b=0.5a$. Negative stresses are compressional and positive stresses are extensional.

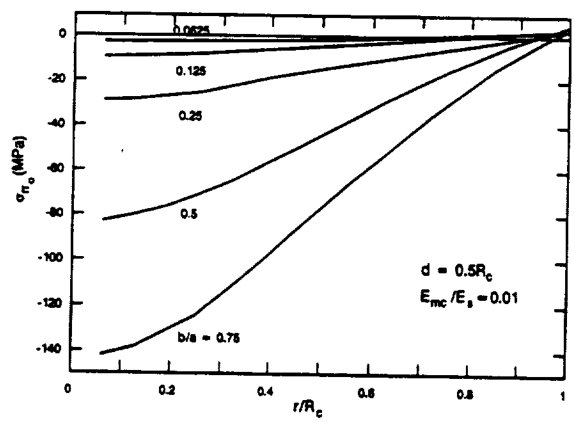

Figure 2. Plot of σ_{rro} vs. r/R_c for a range of magma chamber aspect ratios (b/a) assuming $a=R_c$ and $d=0.5R_c$. Note that the transition from compression (-) to extension (+) is not sensitive to this parameter except for very small b/a.

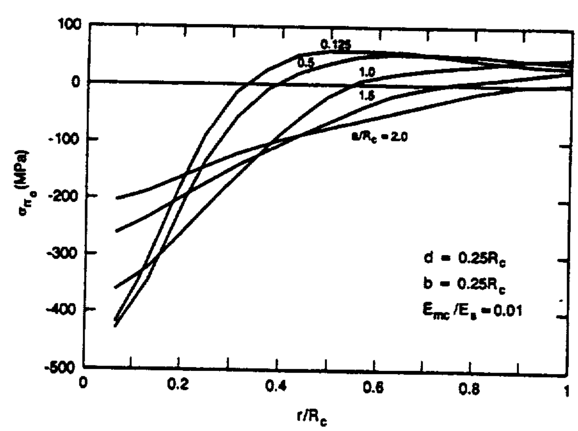

Figure 3. Plot of σ_{rro} vs. r/R_c for a range of magma chamber widths (a) assuming $b=d=0.25R_c$. Note that a wide magma chamber undergoes the transition from compression (-) to extension (+) at greater distances from the crater center than a narrow magma chamber. Therefore a chamber with $a>R_c$ must be shallower than a chamber with $a=R_c$ to explain the transition from concentric ridges to concentric graben at r~$0.5R_c$ in the Olympus Mons caldera.

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